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Contrast gain mechanism or transient channel? Why the effects of a background pattern alter over time

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Abstract

If a brief test pulse is presented on a prolonged background pedestal, it is strongly masked if presented at the start of the pedestal, and is only weakly masked if presented 200 ms after the start. This has been suggested to occur due to contrast gain mechanisms that reduce the representation of the pedestal and therefore reduce its masking effects. We show here that the effect is due to the large transient in contrast that accompanies the onset of the pedestal. We find similar masking at pedestal offset, when the pedestal is continually flickered, or when pedestal and test have a high spatial frequency. These results were all predicted on the basis of sustained and transient channels. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Human suprathreshold vision involves major non-linearities. Popular amongst these is the notion of a divisive gain control (Morrone & Burr, 1986; Burr & Morrone, 1987; Bonds, 1991; Ross & Speed, 1991; Heeger, 1992; Snowden & Hammett, 1992; Ross, Speed, & Morgan, 1993; Wilson & Humanski, 1993; Foley, 1994; Snowden & Hammett, 1996). Recently, the time course of gain control has been examined by presenting a very brief stimulus. If the gain control takes some time to operate, then such brief stimuli may allude it, and we can compare the system with and without this gain control.

Wilson and Humanski (1993) measured threshold elevation that occurred due to prior adaptation to a high contrast stimulus. They report that a brief stimulus suffered little or no threshold elevation, whilst a more prolonged stimulus did. They hypothesised that adaptation might work through a change in a gain control mechanism that is not seen if the stimulus is too

brief. However, other reports show that brief stimuli are affected by contrast adaptation (Foley & Boynton, 1993; Harvey & Greenlee, 1993; Hammett & Snowden, 1995). The study of Hammett and Snowden noted an alternative explanation based upon the notion of sustained and transient channels. Brief stimuli may be detected at thresholds due to their onsets and offsets (Tolhurst, 1975), or in other words due to their high temporal frequencies. Therefore, if one adapts to a low temporal frequency, but tests with a brief pattern, there is no threshold elevation. Hammett and Snowden (1995) predicted and showed that adapting to a flickering pattern does elevate thresholds for brief stimuli. Sustained channels prefer higher spatial frequencies (Legge, 1978). Hammett and Snowden (1995) showed that substantial threshold elevation is found for brief test stimuli at high spatial frequencies even for stationary adapting patterns. Thus, the data were accounted for by the notion of sustained and transient channels and therefore have little to say about feedback gain control.

The time course of gain control has also been examined by the looking at the effects of a sustained pedestal pattern upon sensitivity to a brief test pattern (Wilson

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& Kim, 1998). Test patterns were presented at either the start (0 ms) of the pedestal pattern or 200 ms after its onset. They noted much greater elevation due to the mask at 0 ms than 200 ms. Wilson and Kim (1998) argue that the difference between testing at 0 and 200 ms into the mask is that divisive gain control takes some time to commence and hence is small or absent at 0 ms but near its maximum by 200 ms. At the commencement of the stimulus, there is a strong transient response to the pedestal pattern so that the test pattern has to produce a large response in order to evoke a noticeable incremental response (and it therefore needs a large contrast to do this). As the gain control reduces the response to the pedestal over time, the test pattern needs to produce less response in order to have a noticeable incremental response (and therefore needs less contrast).

However, this pattern of results could also be explained in terms of masking within sustained and transient channels, with a constant masking over time. The onset of the masking pattern is a large transient in contrast and should therefore produce a strong response in transient channels. If brief stimuli are detected by transient channels, we should expect a great deal of masking at the onset of the pedestal. However, if the test is presented well after the onset, the effects of the onset will have diminished (due to the time course of masking processes — see Georgeson & Georgeson, 1987) and hence little elevation of thresholds.

2. Experiment 1

In this experiment, we presented a brief pulse of a stationary grating (termed 'test') and measure the amount of contrast needed for its detection. The pulse was presented upon a background of another grating (termed 'pedestal') of duration 400 ms. To distinguish between these two theories, we examine two conditions:

1. What happens near the offset of the pedestal? The 'transient channel' hypothesis predicts that the offset of the pedestal should produce a large amount of masking—the same amount as at the onset of the pedestal. The 'divisive gain' hypothesis predicts that we should only get a small amount of masking — the same amount as in the middle of the pedestal.
2. What happens if the pedestal continues to activate the transient channel throughout its time course (done by flickering the pedestal)? The 'transient channel' hypothesis predicts that thresholds will be strongly and equally elevated at all times during the pedestal. The 'divisive gain' hypothesis predicts the same pattern of performance as for a stationary stimulus (i.e. strong masking near the start that diminishes with time).

2.1. Methods

2.1.1. Apparatus and stimuli

The stimuli were sinusoidal luminance gratings generated by a Cambridge Research Systems VSG2.1 image generator using 14 bit DACs. They were displayed on a CRT (Joyce Electronics, Cambridge, UK). The display had a white phosphor (P4), a mean luminance of 150 cd m⁻² and was refreshed at 100 Hz. The contrast of the gratings was gamma corrected by internal look-up tables to ensure linear performance over all the range of luminances used.

The background and test stimuli were both displayed side by side upon the monitor. They were both vertical gratings, but their spatial frequencies, temporal frequencies, phases, contrasts and timings were set independently by software. The spatial superposition of test and background was achieved via mirrors. The image of the test passed first through a Dove prism, and was then reflected by a front-silvered mirror to a half-silvered mirror and then to the eye. The image of the background passed directly to the half-silvered mirror and then to the eye. It was restricted in size by a black cardboard tube that served to block out stray light and thus subtended a circle of 10.8° diameter from the viewing distance of 38 cm. The test stimulus was restricted in size by the Dove prism so that it subtended a square of side 6.7° whose centre was at the centre of the background stimulus. Note that in this region, where the patterns were superimposed the luminance of the screen was 300 cd m⁻². The Dove prism also was set to produce a small difference in orientation of 10° between the test and background patterns. This ensured a range of phases between the test and background within each trial. The spatial phases of the gratings were also randomised individually from trial to trial.

On each trial the background pattern was presented twice separated by 500 ms. Each presentation lasted for 400 ms, and all changes in contrast were abrupt. In one of these two intervals the test stimulus occurred. The test stimulus was presented for one refresh (10 ms) and occurred 0, 100, 200 or 390 ms after pedestal onset. Note that the pedestal was present for 400 ms, and so the test occurring at 390 ms was temporally coincident with the last frame of the pedestal. We used two pedestal conditions of 0 and 16 Hz flicker (note the test is always at 0 Hz). The contrast of the pedestal (16%) was chosen to produce large masking effects whilst not going beyond the limitations of test contrasts the equipment could provide.

2.2. Procedure

Each trial consisted of two intervals, both of which contained the pedestal, but only one (randomly chosen from trial to trial) contained the test pattern. The

subject's task was to indicate in which interval they believed the test patterned had occurred. The contrast of the test pattern was controlled via a staircase procedure. The contrast for the first trial was chosen by the experimenter to be a value well above the expected threshold. Correct responses decreased contrast for the next trial by 1 dB whereby incorrect responses increased contrast by 3 dB. Trials from the four staircases, corresponding to the four timings of the test stimulus relative to the background, were randomly interleaved. Each staircase ran for 32 trials so that each block consisted of 128 trials.

For each timing condition, the percentage of correct responses at each contrast level presented was calculated and then fit by Probit analysis (Finney, 1971) to estimate the contrast that subjects achieved 75% correct performance. Three such measurements were taken, and the data points and errors bars represent the mean and standard errors of these.

2.3. Subjects

Two subjects were used. One subject was the author (RS — male, aged 34) and a research assistant (TF — male, aged 22). TF wore corrective lenses during all the experiments.

2.4. Results

Fig. 1 plots the threshold contrast (in dB relative to a contrast of 1) as a function of the timing of the test

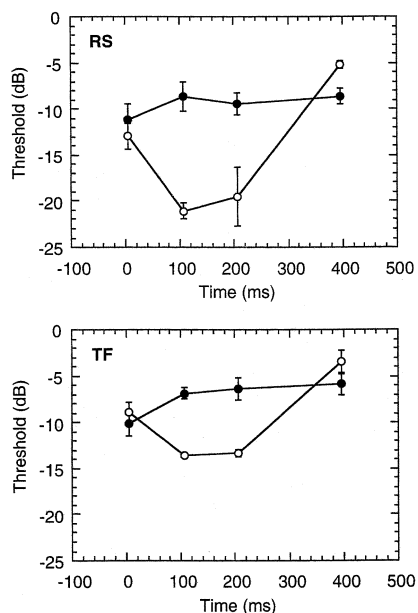


Fig. 1. Threshold contrast is plotted as a function of the time from the onset of the pedestal pattern from experiment 1. The open symbols are for data for a stationary pedestal, and the solid symbols are for a pedestal that was counter-phased flickered at 16 Hz. Error bars represent ± 1 S.E.M.

stimulus. In agreement with Wilson and Kim (1998) (when the pedestal is stationary open symbols), thresholds for tests at 100 and 200 ms are lower than at 0 ms. However, thresholds are much greater for tests at 390 ms, right at the end of the pedestal. When the pedestal was flickered throughout its presentation, thresholds were elevated approximately equally at each test interval.

3. Experiment 2

It is well documented that the sustained channel has a greater sensitivity at high spatial frequencies in relation to the transient channel (Kulikowski & Tolhurst, 1973; Tolhurst, 1973, 1975; Legge, 1978; Anderson & Burr, 1985; Hess & Snowden, 1992; Snowden & Hess, 1992), so it is possible that if a high spatial frequency test pattern is used, it will be detected at threshold by the sustained channel despite its brevity. Thus, there should be strong threshold elevation throughout the time course of such a high spatial frequency pedestal. The divisive feedback model predicts similar results at high spatial frequencies than at low spatial frequencies.

3.1. Methods

A single circular patch of grating (diameter = 4°) was presented on the screen and was viewed directly by the observer. The patch had a contrast of 16% and served as the pedestal. The test pattern was identical to the pedestal pattern save for its contrast and timings (all timings were as in experiment 1). As the test and patch are identical, the task was to detect a brief contrast increment in the pedestal pattern. All other factors were as in experiment 1.

3.2. Results

Fig. 2 plots threshold contrast as a function of the timing of the test stimulus. The results for the 1 cyc deg^{-1} stimulus are similar to experiment 1 save that all thresholds are lower due to the different apparatus and size of test pattern. When the spatial frequency of the patterns was high (8 cyc deg^{-1}), strong masking was apparent throughout the time course of the background presentation with even a hint of increased masking as SOA increases.

3.3. Discussion

Our results show:

1. Both temporal onsets and offsets of the pedestal produce strong masking of brief test stimuli compared to the central portion for low spatial frequencies.

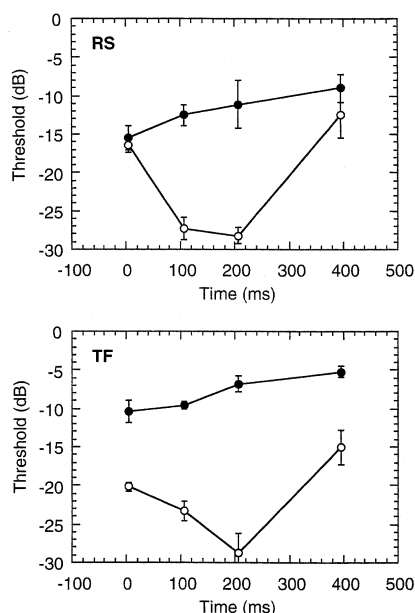


Fig. 2. Threshold contrast is plotted as a function of the time from the onset of the pedestal pattern from experiment 2. The open symbols are for data for a pattern of 1 cyc deg⁻¹, and the solid symbols are for a pedestal of 8 cyc deg⁻¹. Error bars represent ± 1 S.E.M.

2. Flickering the pedestal produces strong masking at all times.
3. At high spatial frequencies, a stationary pedestal produces strong masking at all times.

The pattern of results is that predicted by the already well-established notion that the visual system contains both transient and sustained channels whose spatial frequency sensitivity is somewhat different. Brief test patterns of low spatial frequency are detected by a transient channel and are thus only masked by stimuli that also activate this channel, i.e. at the onset or offset of stationary patterns, or flickering patterns. Brief patterns of sufficiently high spatial frequency are detected by a sustained channel and are therefore masked by stimuli that also activate this channel. Hence, these data are concomitant with the notion of masking within sustained and transient channels, with no change in the amount of masking taking place over time.

We have presented predictions based upon the simple notion that masking only takes place within a channel. This is clearly a highly simplified model, and there are data that convincingly demonstrate that this is not the whole story (Foley, 1994; Snowden & Hammett, 1998). Masking could occur due to response compression or through gain control mechanisms acting within a channel or across channels (or any combination of such mechanisms). The present experiments do not address how this masking is taking place and certainly do not rule out the existence of gain control mechanisms for

which there is ample evidence elsewhere (Morrone & Burr, 1986; Burr & Morrone, 1987; Bonds, 1991; Ross & Speed, 1991; Heeger, 1992; Snowden & Hammett, 1992, 1996; Ross et al., 1993; Wilson & Humanski, 1993; Foley, 1994).

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